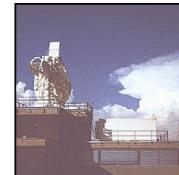
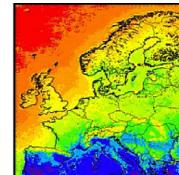
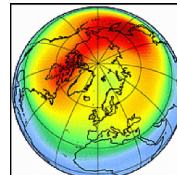


# 1D and 3D radiative transfer – a MYSTIC experience with libRadtran

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# *libRadtran*

<http://www.libradtran.org>

1991 – 2005

*Mayer and Kylling, ACP 5, 1855–1877, 2005.*

- Flexible and comprehensive radiative transfer package
- Spectrally resolved in the UV/visible, line-by-line, quasi-spectral (LOWTRAN), and correlated-k in the solar and thermal infrared
- Irradiance, actinic flux, radiance, heating rates
- User-friendly interface to various solvers:  
*disort 1.3 / 2.0, sdisort, twostr, sos, polRadtran, (MYSTIC)*
- Compiled and tested under several UNIXes, Mac OSX, and Windows 95/98/NT/XP
- Validated in several intercomparisons

# The libRadtran input file

```
atmosphere_file ./data/atmmod/afglus.dat
solar_file      ./data/solar_flux/kurudz_1.0nm.dat

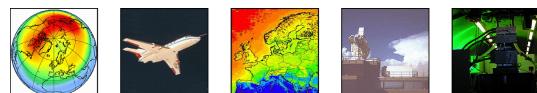
rte_solver disort2      # choose one of about 10 solvers

sza 45                  # solar zenith angle

wc_file ./wc.dat         # water cloud
wc_layer

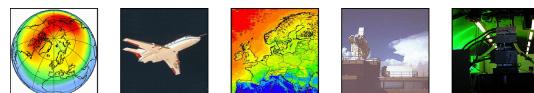
ic_file ./ic.dat         # ice cloud
ic_layer
ic_properties yang

correlated_k kato2       # treatment of molecular absorption
output sum                # sum over wavelength
```

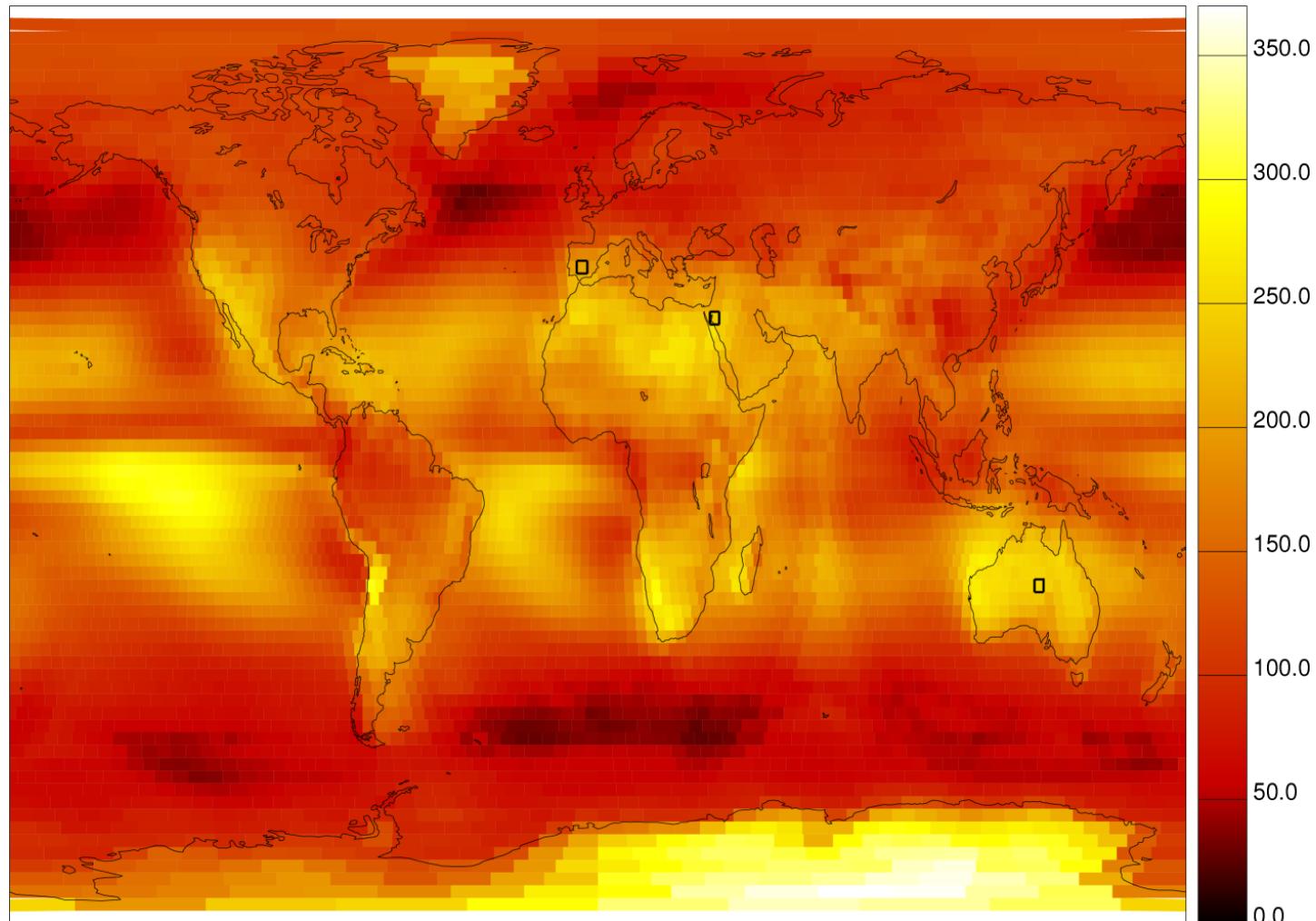


# Current libRadtran applications at DLR

- Remote sensing of water and ice clouds (Luca Bugliaro)
- Simulation of satellite observations (Luca Bugliaro/Tobias Zinner)
- Radiative forcing of aircraft-induced contrail-cirrus (Waldemar Krebs)
- Remote sensing of inhomogeneous clouds (Tobias Zinner)
- Effect of 3D RT on cloud formation (Kathrin Wapler)
- Radiation balance at the tropical tropopause (Ulrich Hamann)
- Direct and global irradiance for solar energy applications (Sina Lohmann)
- Photochemistry in broken clouds (Ronald Scheirer/Bernhard Mayer)



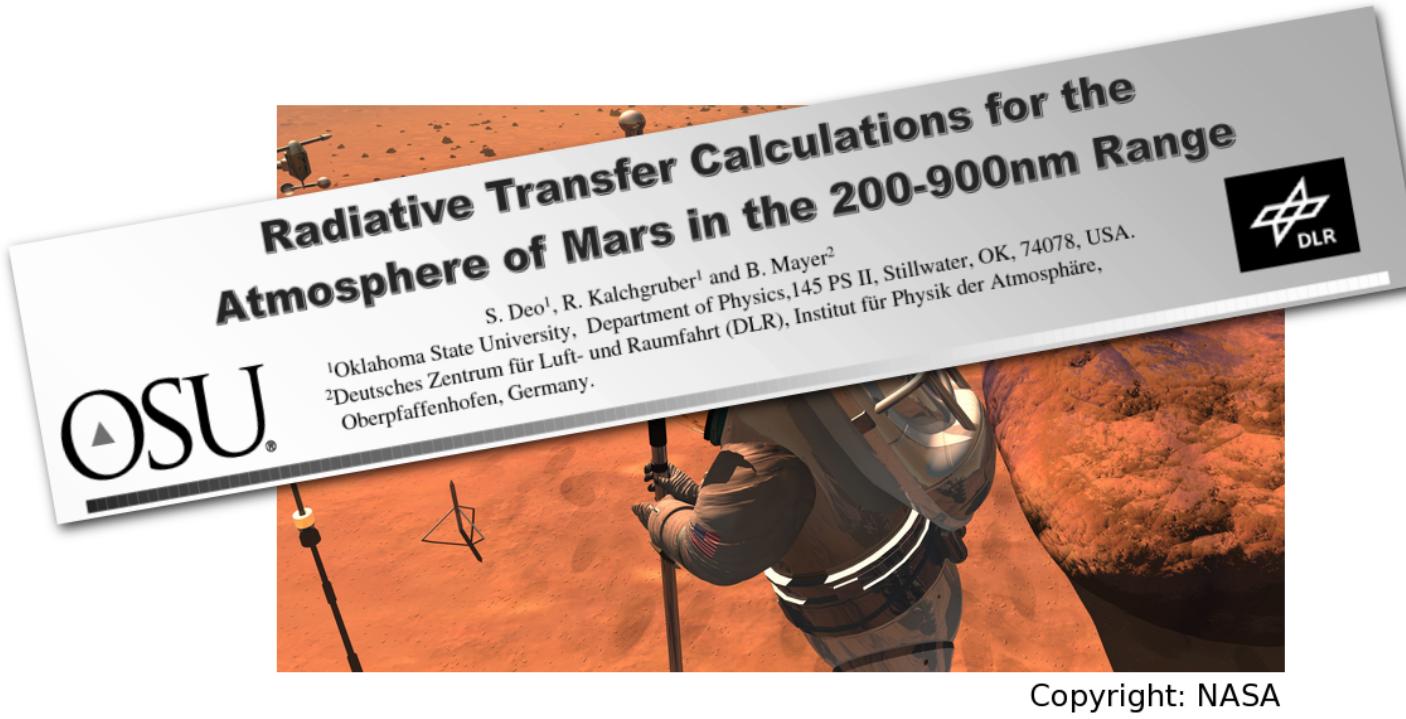
# Example: Direct normal irradiance

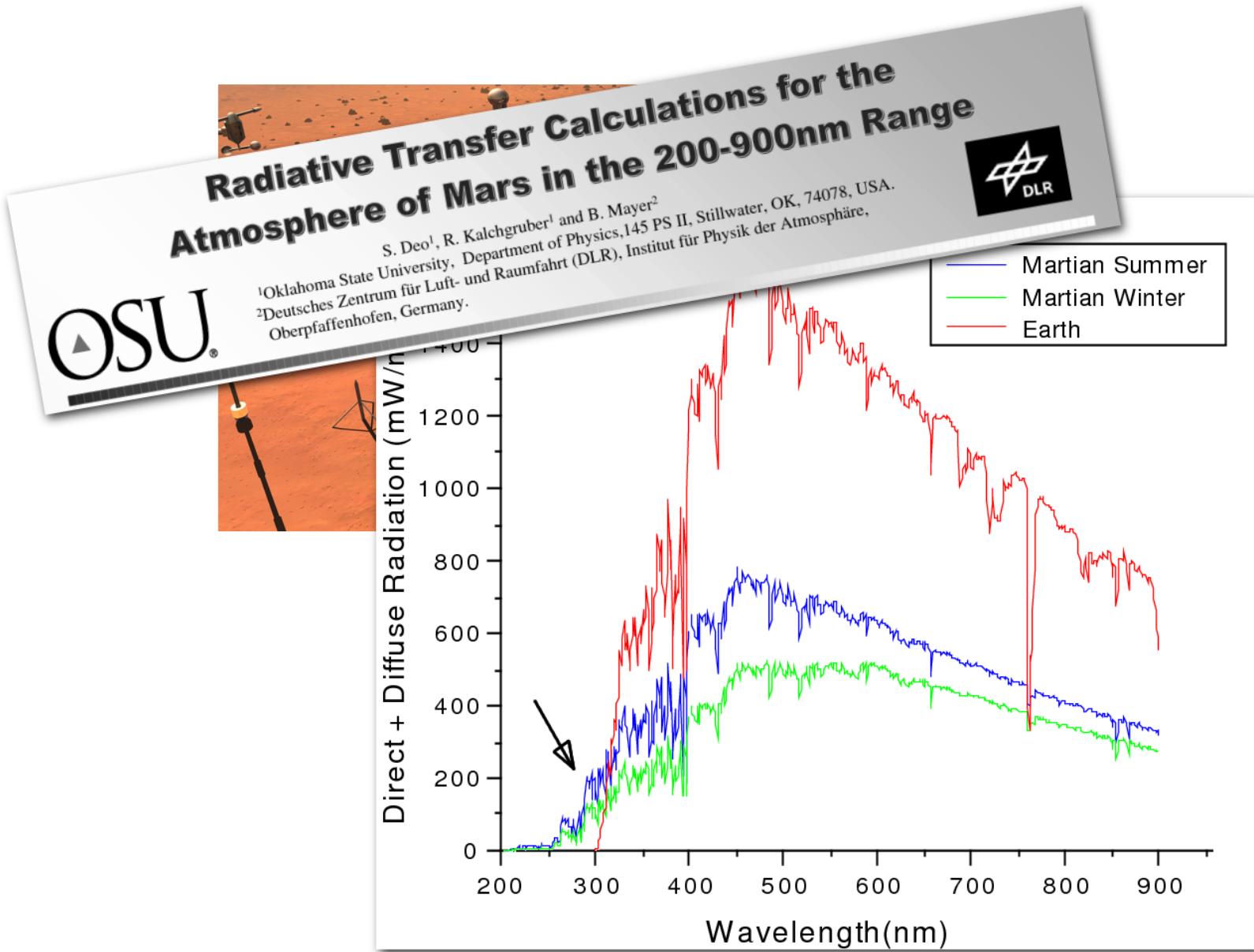


Direct normal irradiance [ $\text{W/m}^2$ ], based on 18 years ISCCP data. Lohmann et al, Solar Energy, in press, 2005.

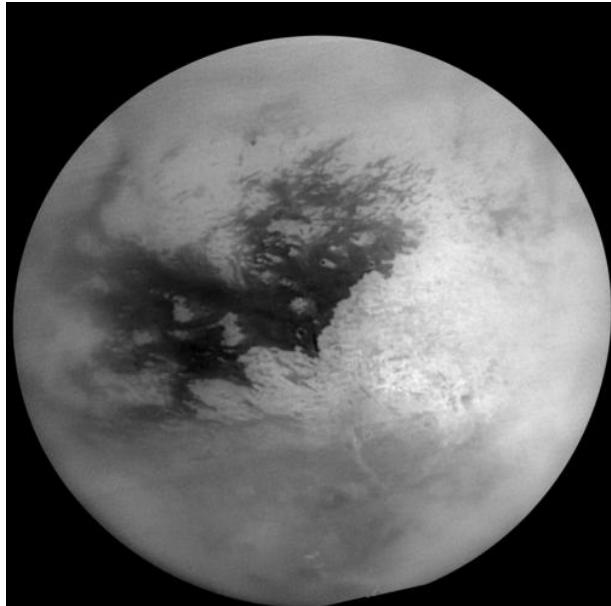


Copyright: NASA

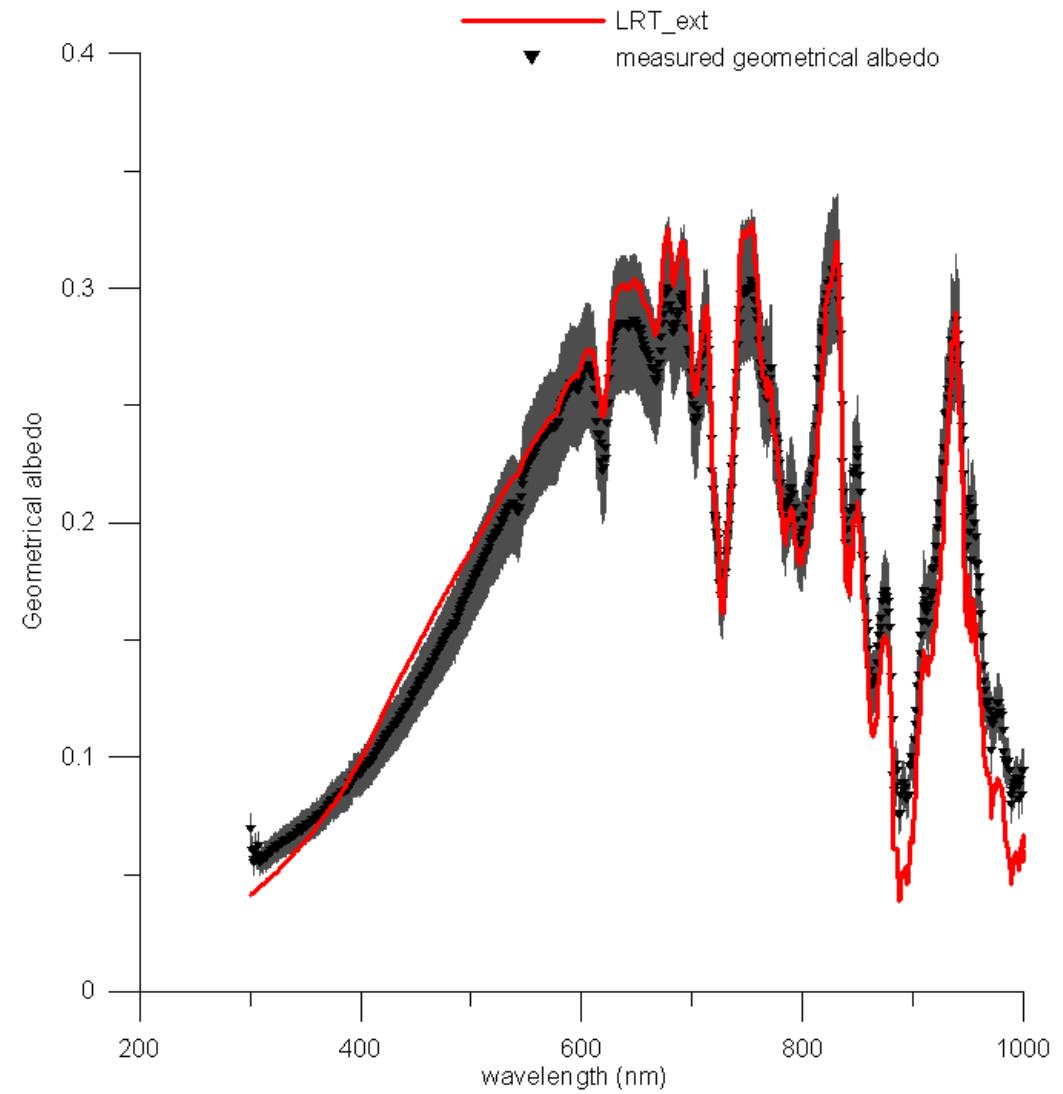




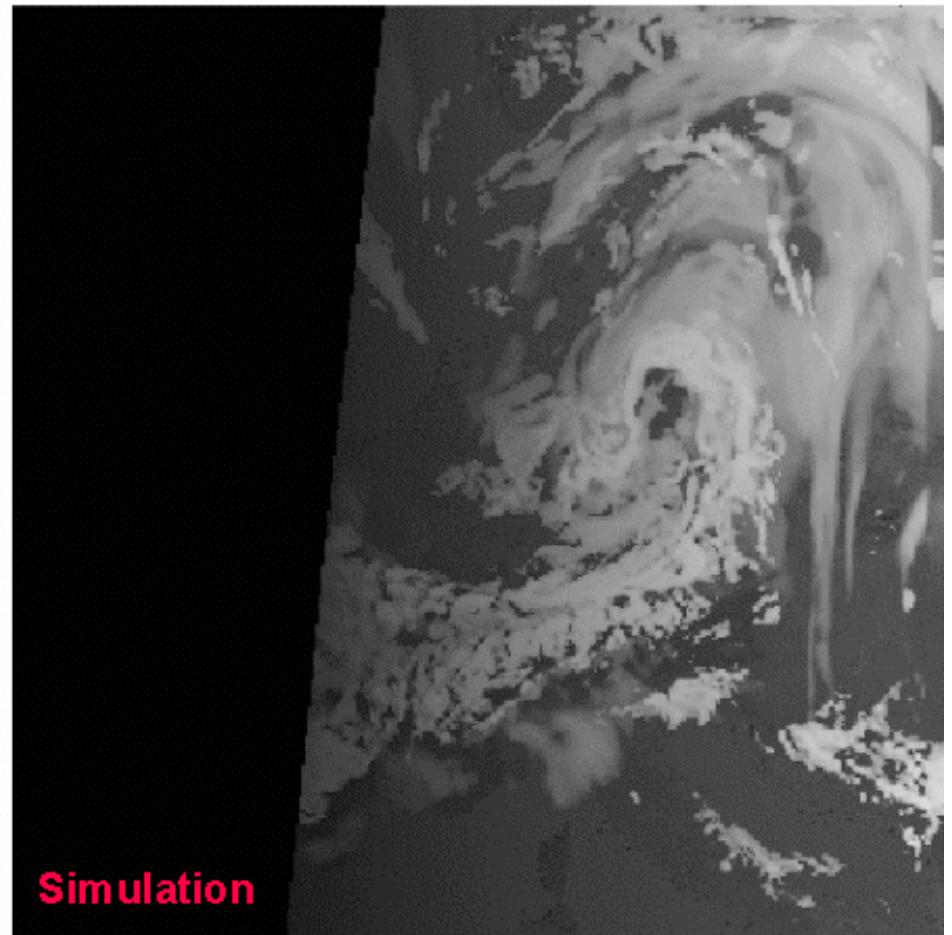
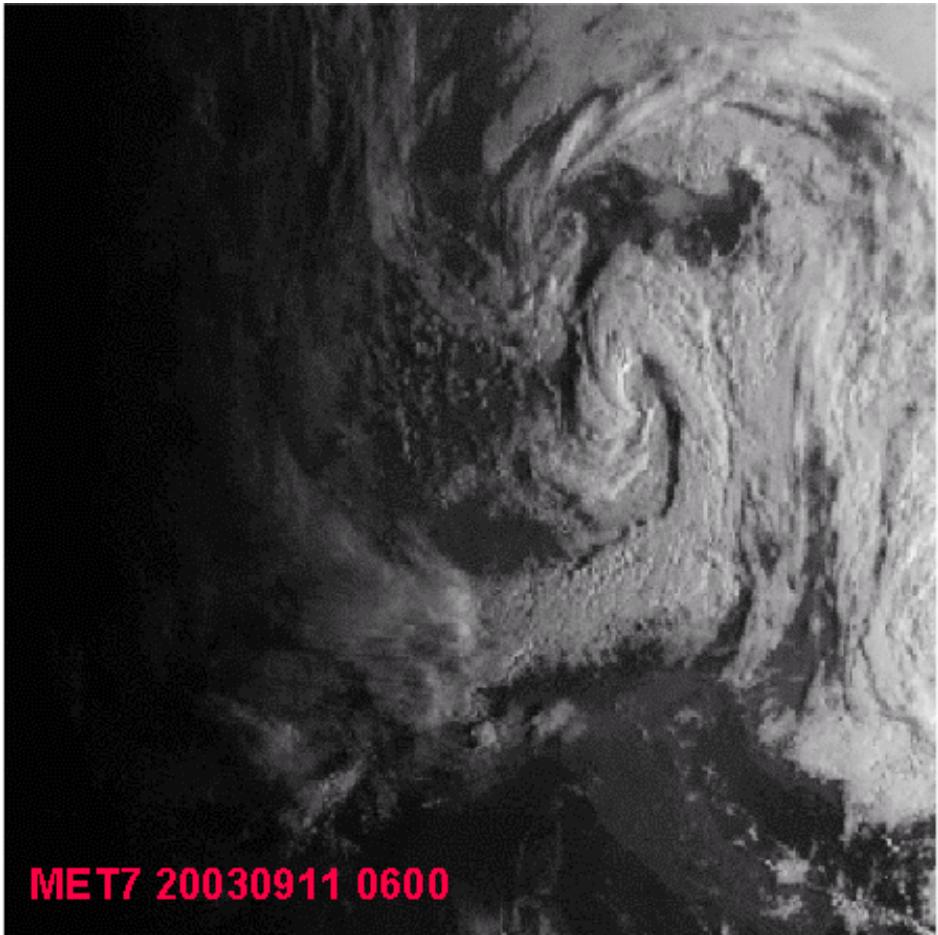
# Example: Remote sensing of Titan using CASSINI-VIMS

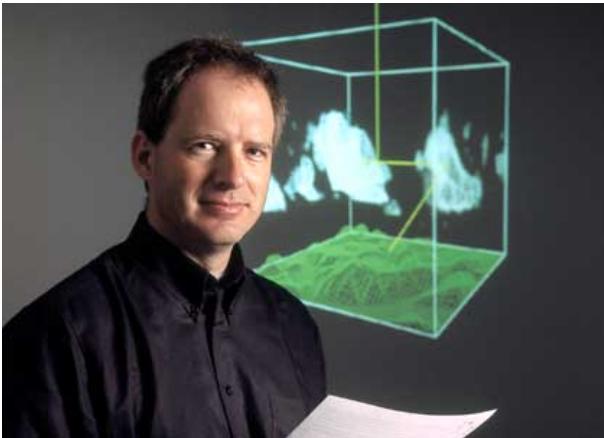


Adriani et al.,  
*Earth, Moon, and Planets*,  
submitted 2005



# Example: Artificial satellite images





Source: Spiegel 35, 2004

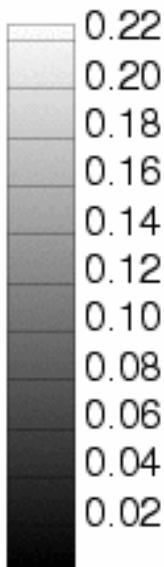
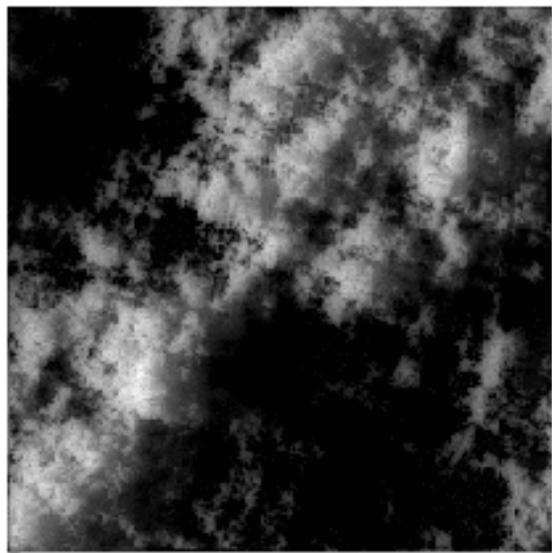
# **MYSTIC: Monte carlo code for the phYSically correct Tracing of photons In Cloudy atmospheres.**

Mayer [1999, 2000]

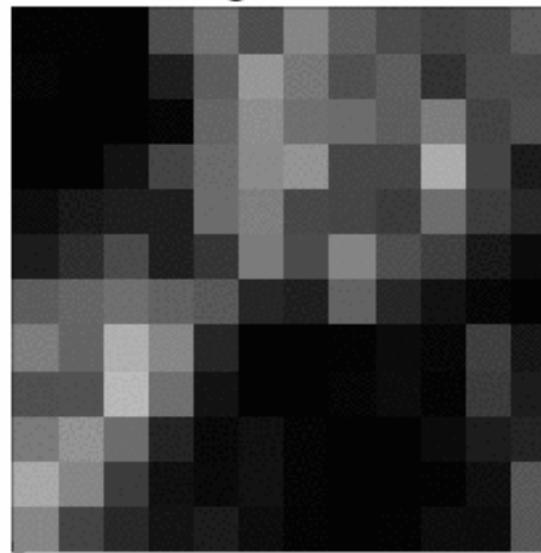
- Forward photon tracing in plane-parallel geometry, without simplifying assumptions
- Solar and thermal sources
- 3D clouds, topography, inhomogeneous albedo, BRDF
- Rayleigh scattering, aerosol, molecular absorption (ozone, CO<sub>2</sub>, ...)
- Runs as part of libRadtran
- Solves all I3RC phase 1 and 2 cases
- Online visualization

# MYSTIC: Test remote sensing methods

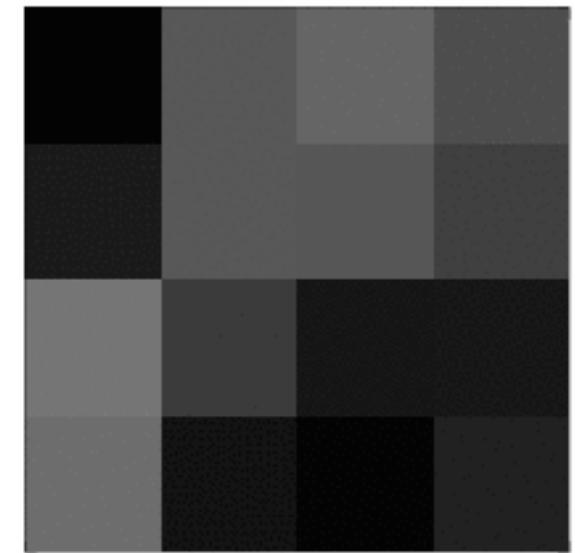
50m resolution



MSG high resolution



MSG low resolution

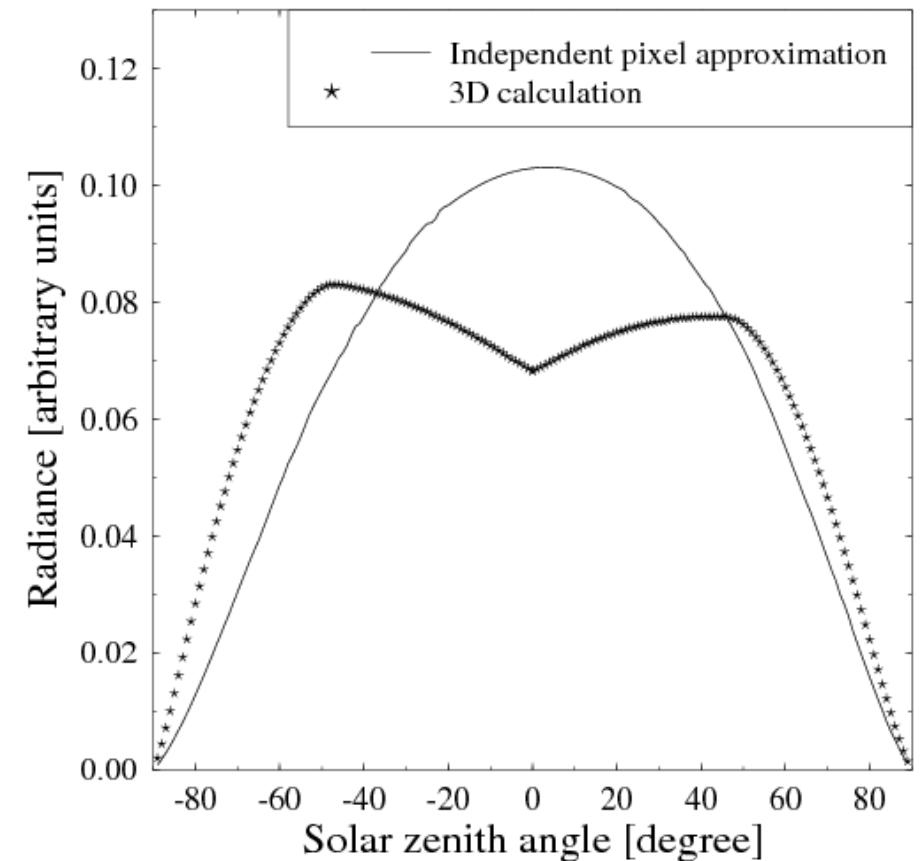


- Test of cloud detection and classification
- Validation of the retrieved microphysical properties

# Cubic clouds - in the 21st century?

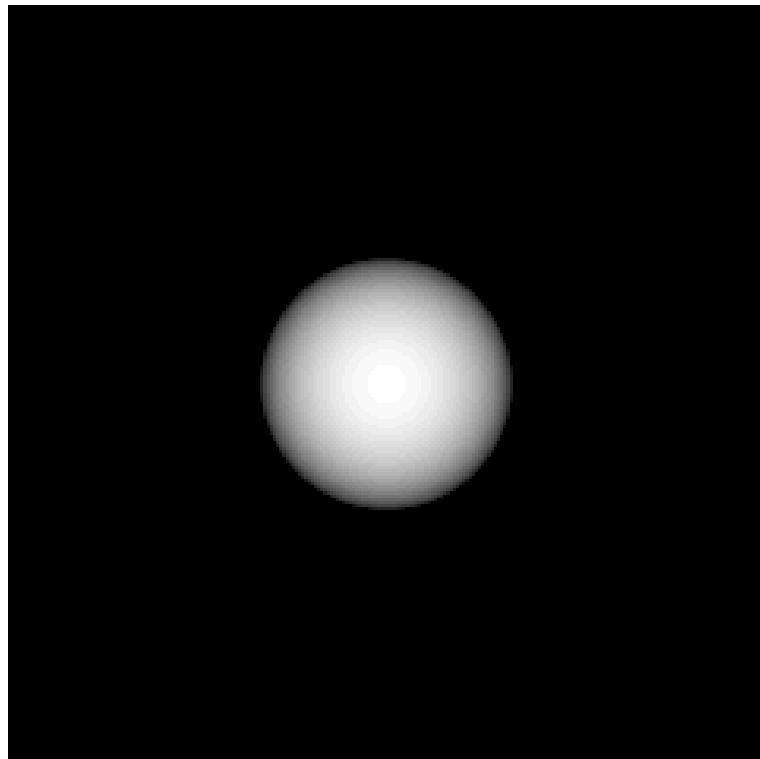
SZA  $90^\circ$  –  $0^\circ$  –  $90^\circ$

Viewing angle  $30^\circ$

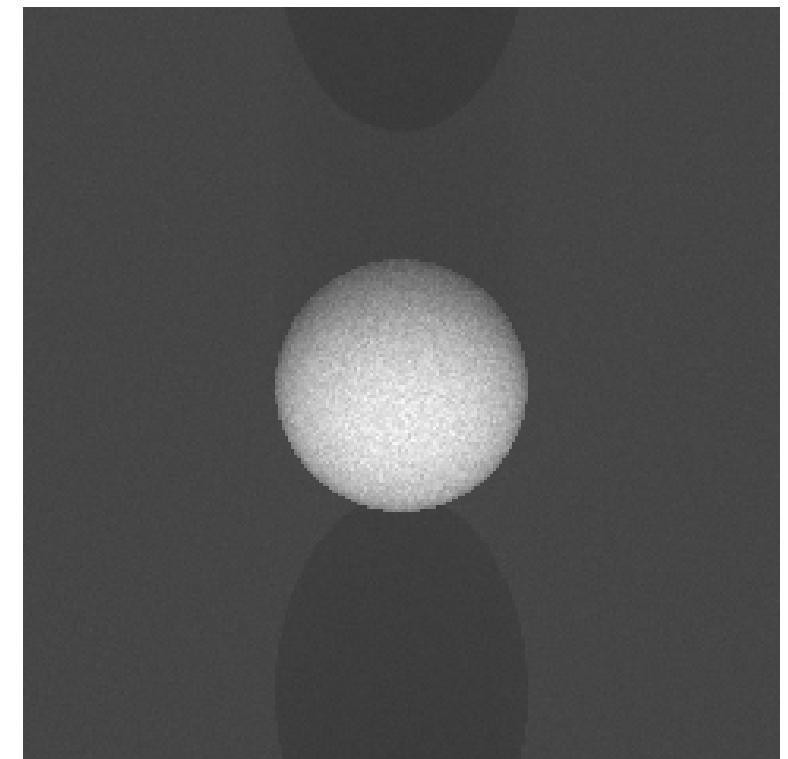


# Spherical clouds - the better alternative?

Optical thickness

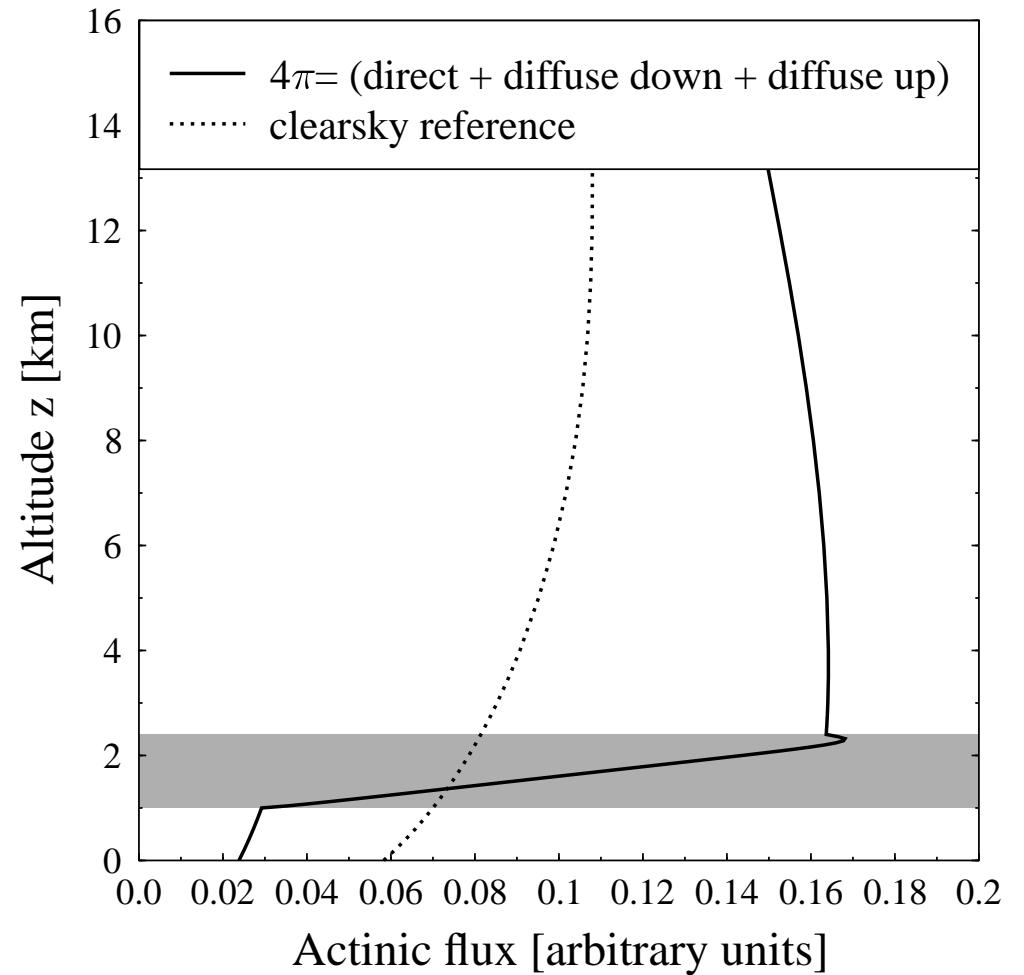
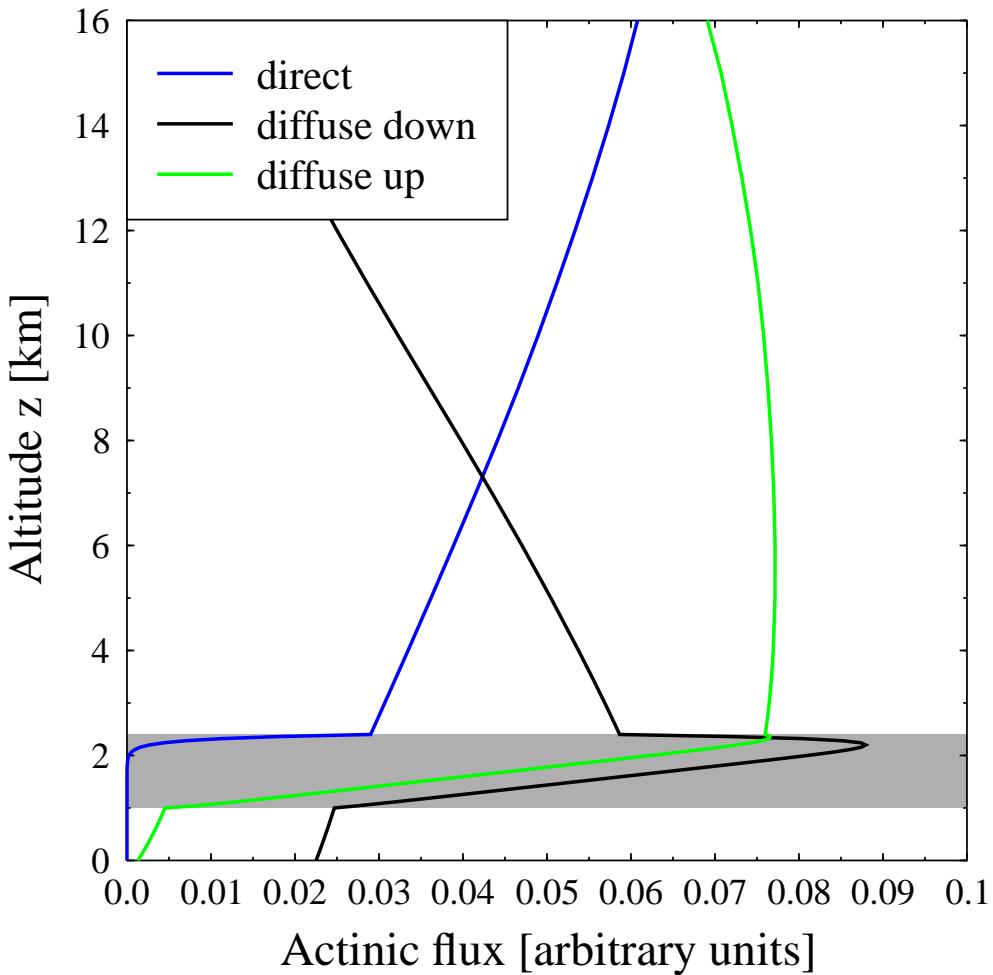


Nadir radiance, SZA = 50°



$240 \times 240 \times 120 =$   
6,912,000 grid cells

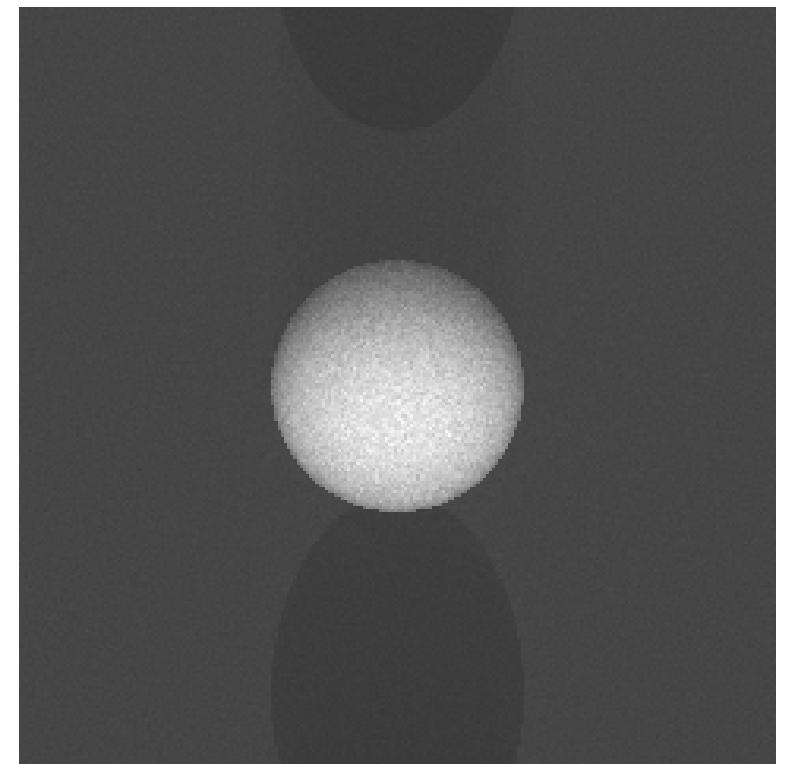
# Spherical clouds - the better alternative?



# Spherical clouds - the better alternative?

Actinic flux

Nadir radiance, SZA = 50°



horizontal cross section

# “Real” clouds

0.6  $\mu\text{m}$  radiance      2.1  $\mu\text{m}$  radiance

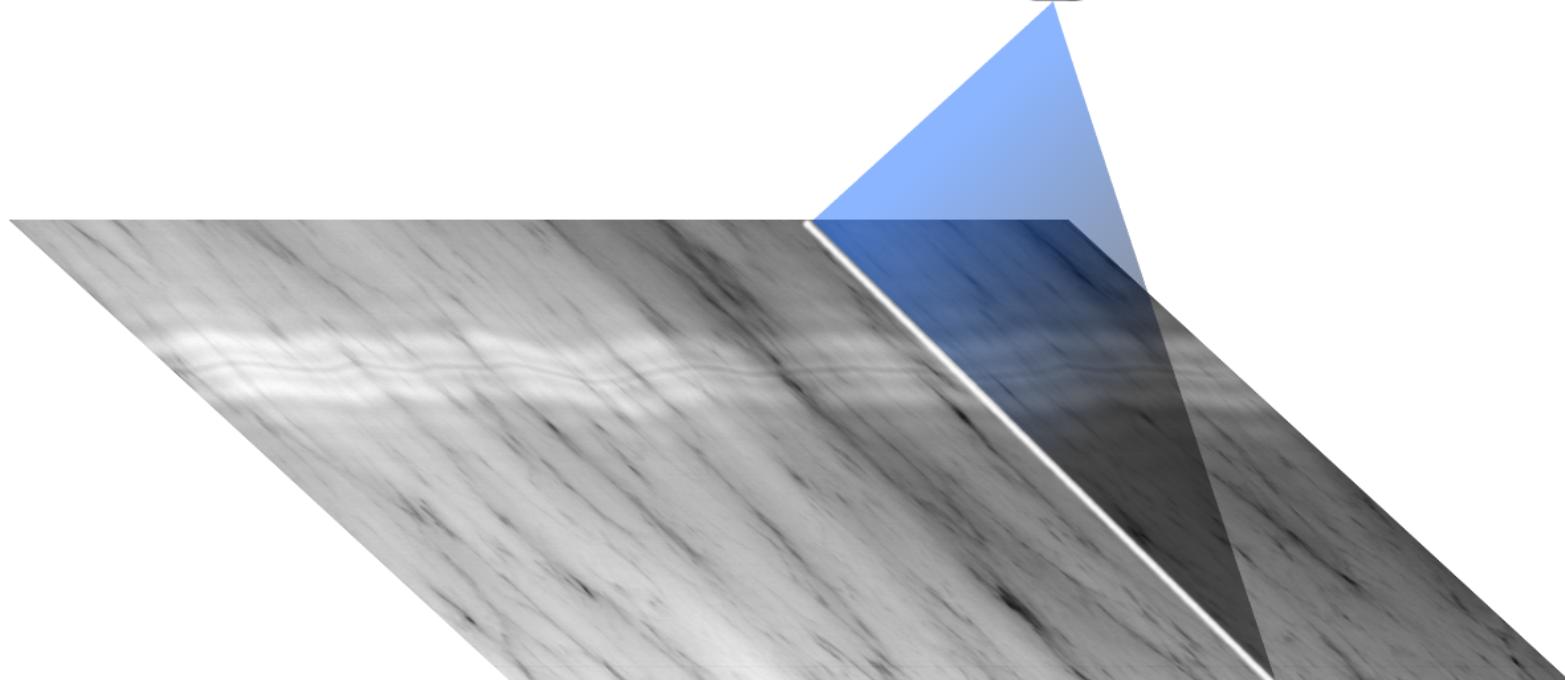
Solar zenith angle 30°

→ Presentation by Tobias Zinner, Wednesday

# The aircraft perspective

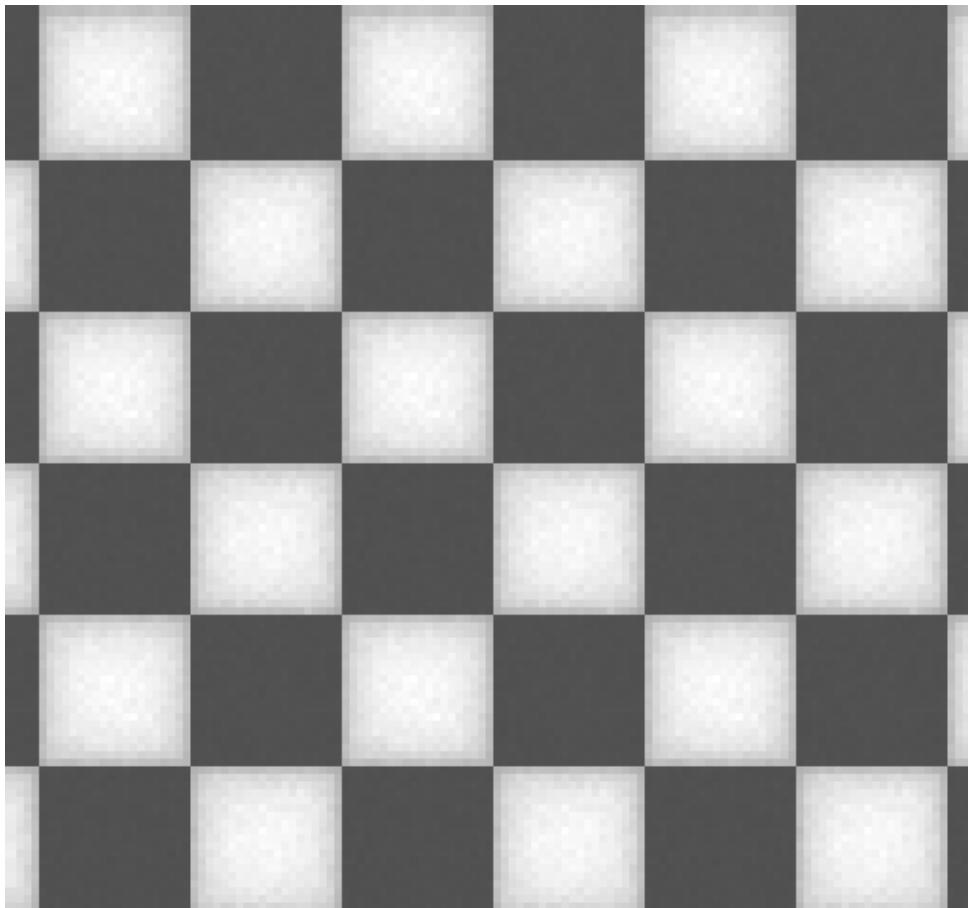
ACE-2 CLOUDYCOLUMN experiment

CASI = compact airborne spectrographic imager  
wavelength 754nm  
angular resolution  $0.07^{\circ}$   
pixel size at cloud top:  $2 \times 75 \text{ m}^2$

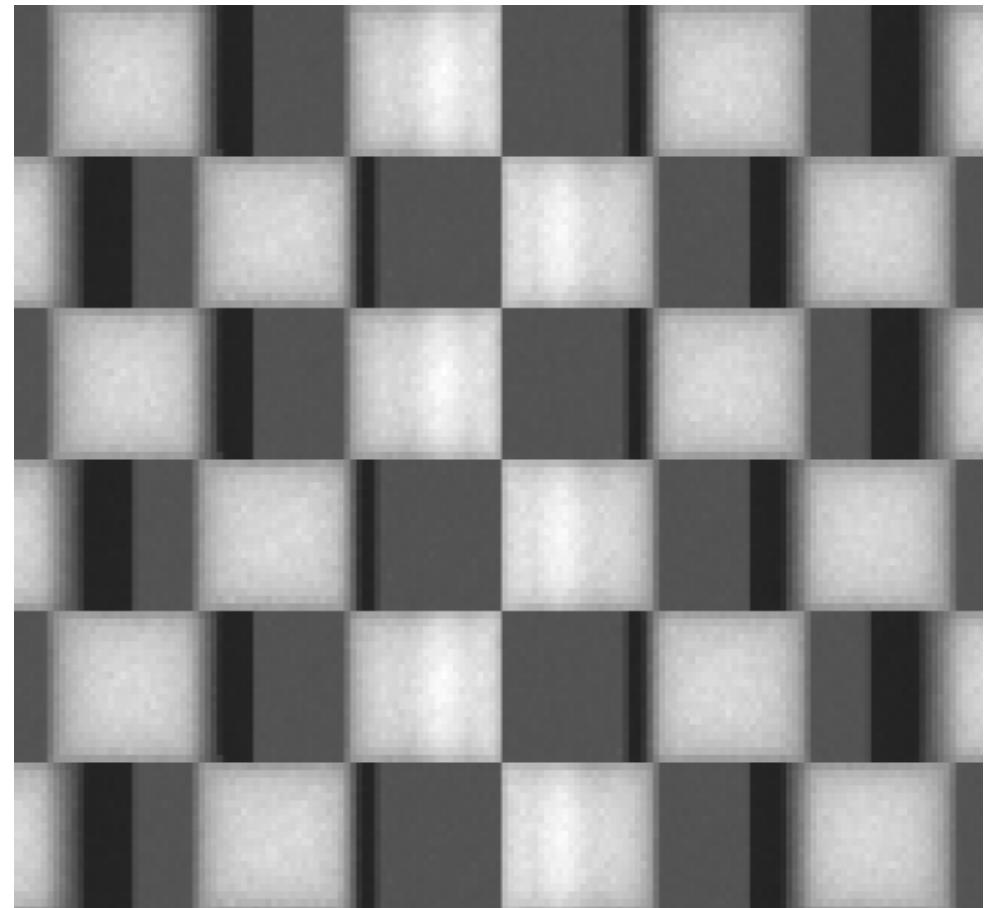


# The aircraft perspective

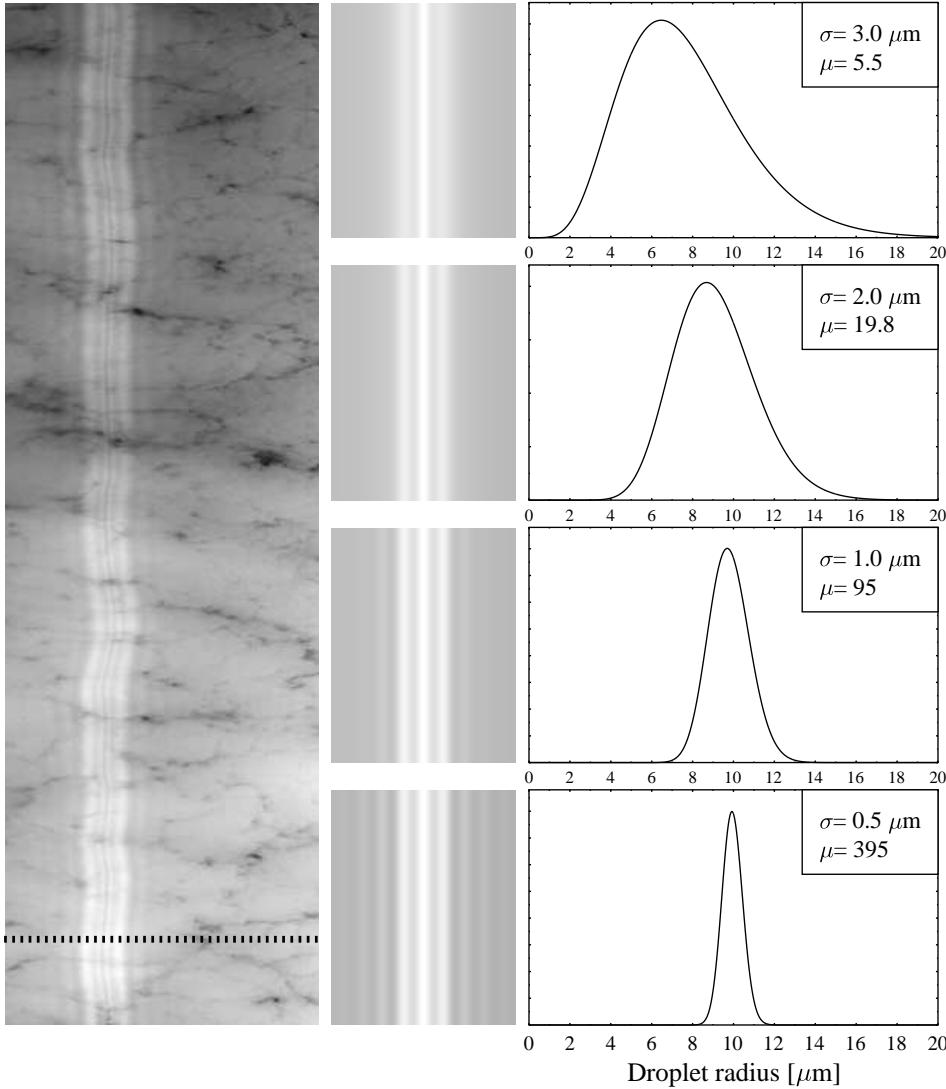
Satellite



Aircraft

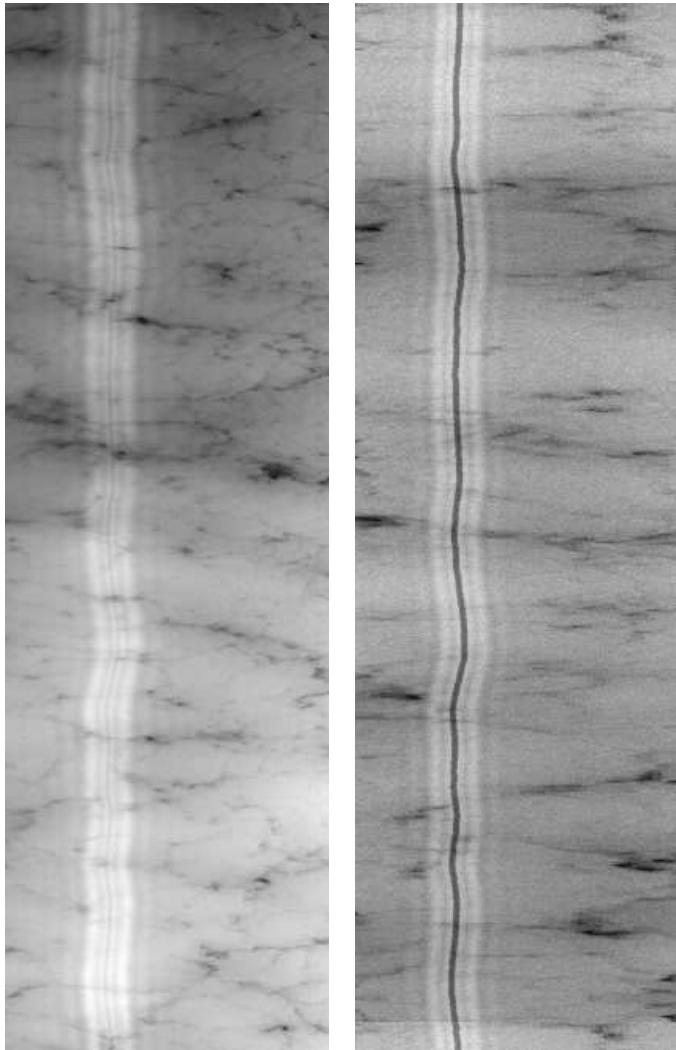


# Observation of the backscatter glory



Mayer, Schröder, Preusker, Schüller:  
Remote sensing of water cloud  
droplet size distributions using  
the backscatter glory: a case study  
*ACP* 4, 1255 – 1263, 2004.

# Retrieval test by sensor simulation

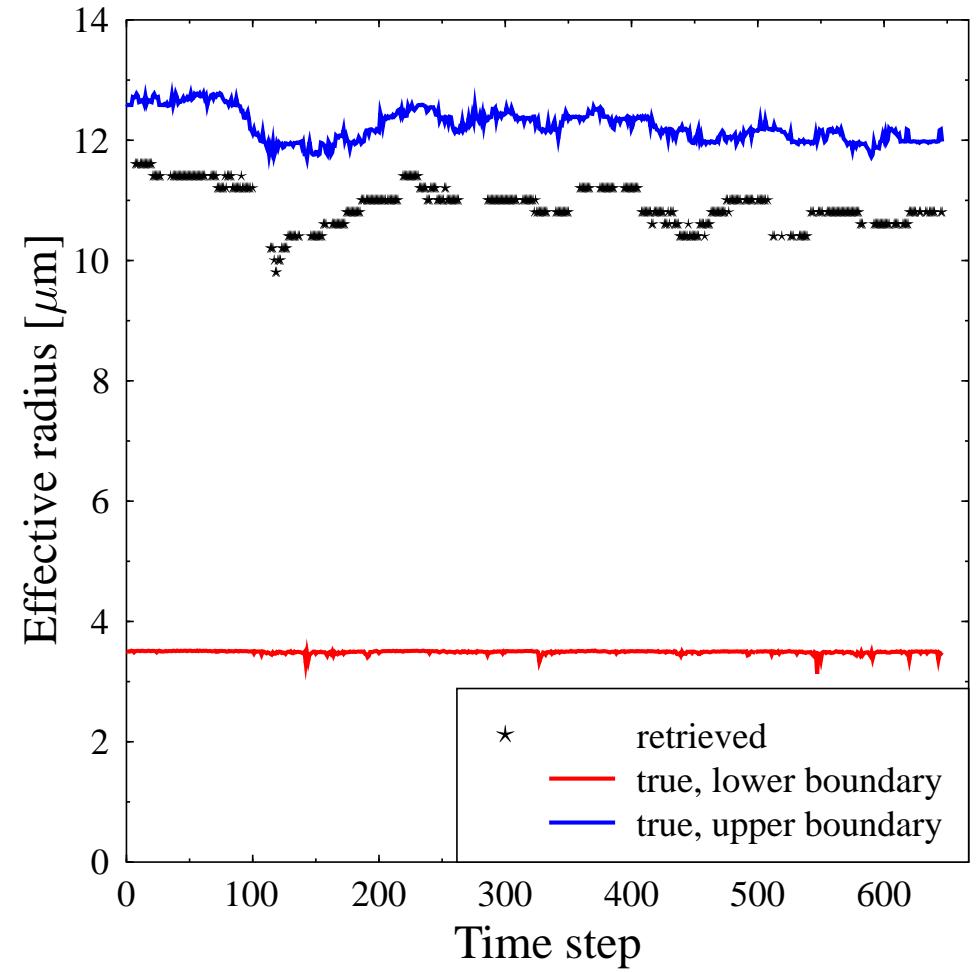
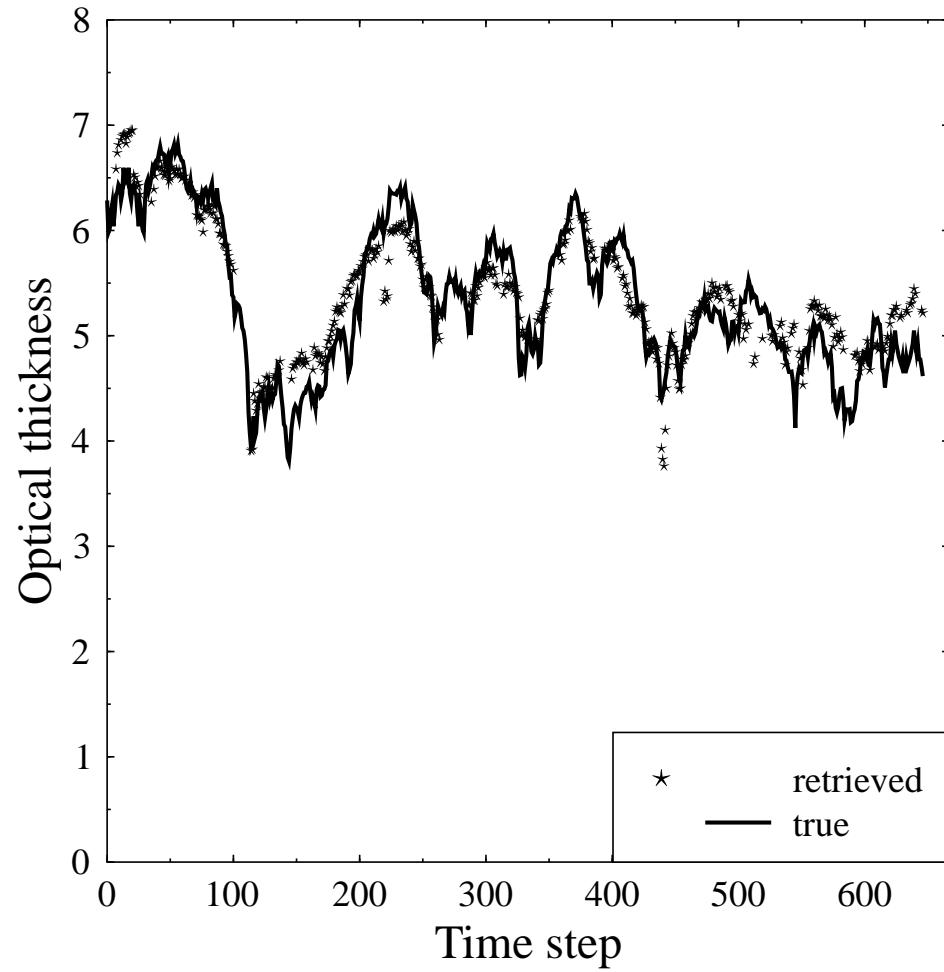


**Left:** Observation

**Right:** Simulation

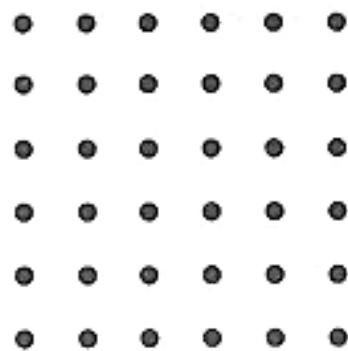
- libRadtran
- RTE solver  
MYSTIC (3D Monte Carlo)
- Cloud data:  
Same day, different flight leg;  
smaller optical thickness

# Retrieval test by sensor simulation

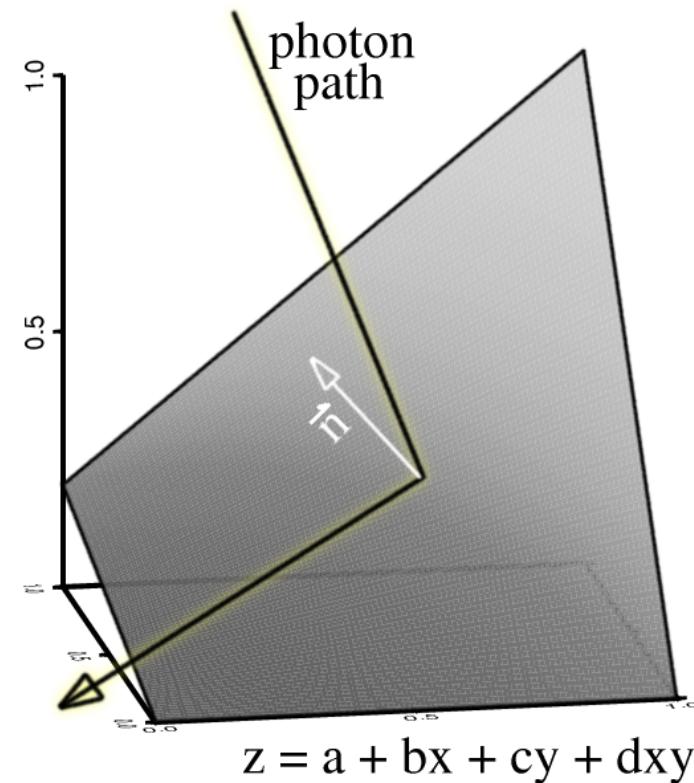
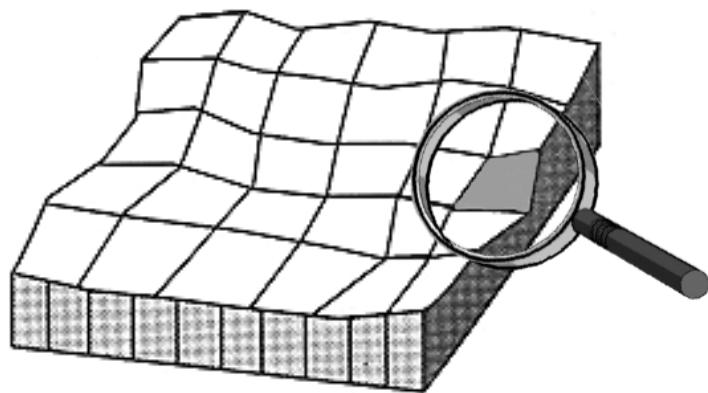


# Surface representation in MYSTIC

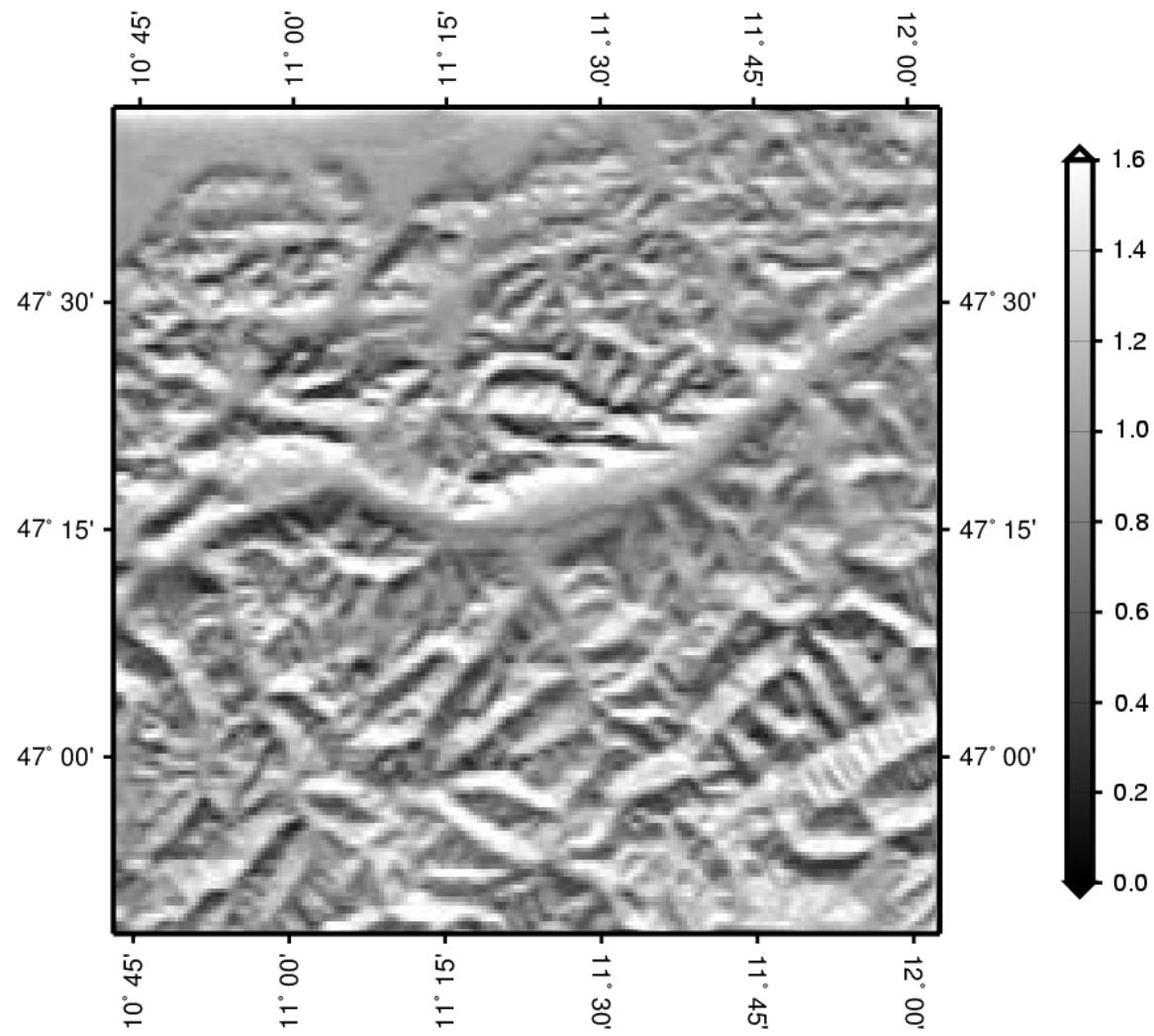
Elevation grid



DEM

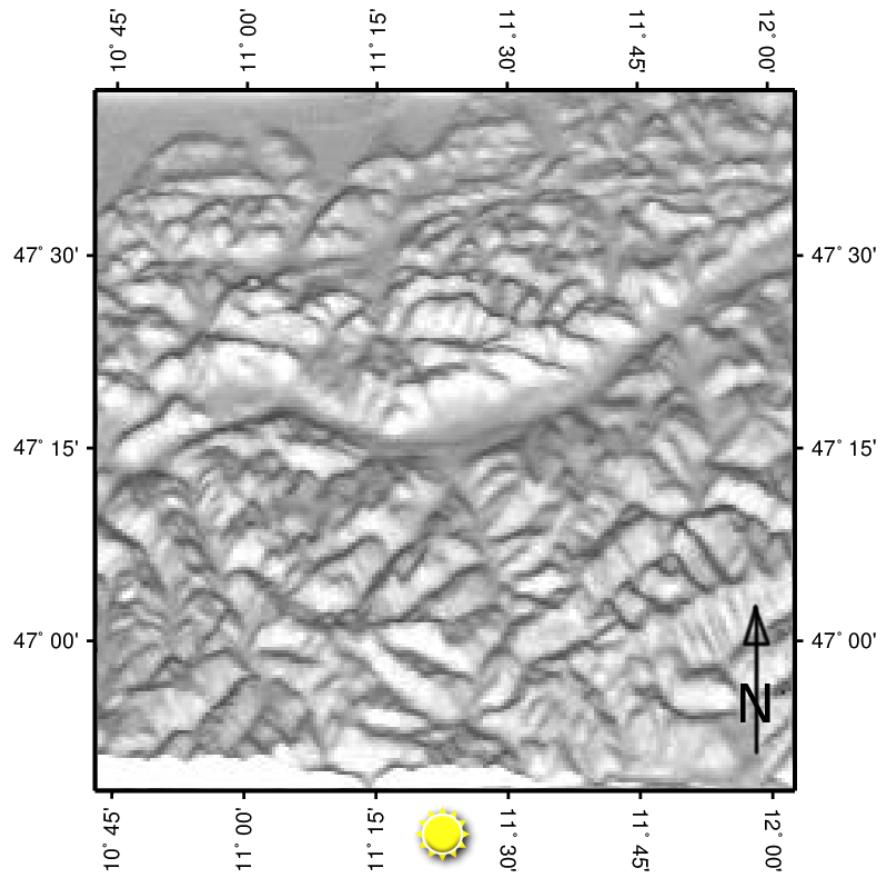


# Surface: Nadir reflectivity at 600 nm

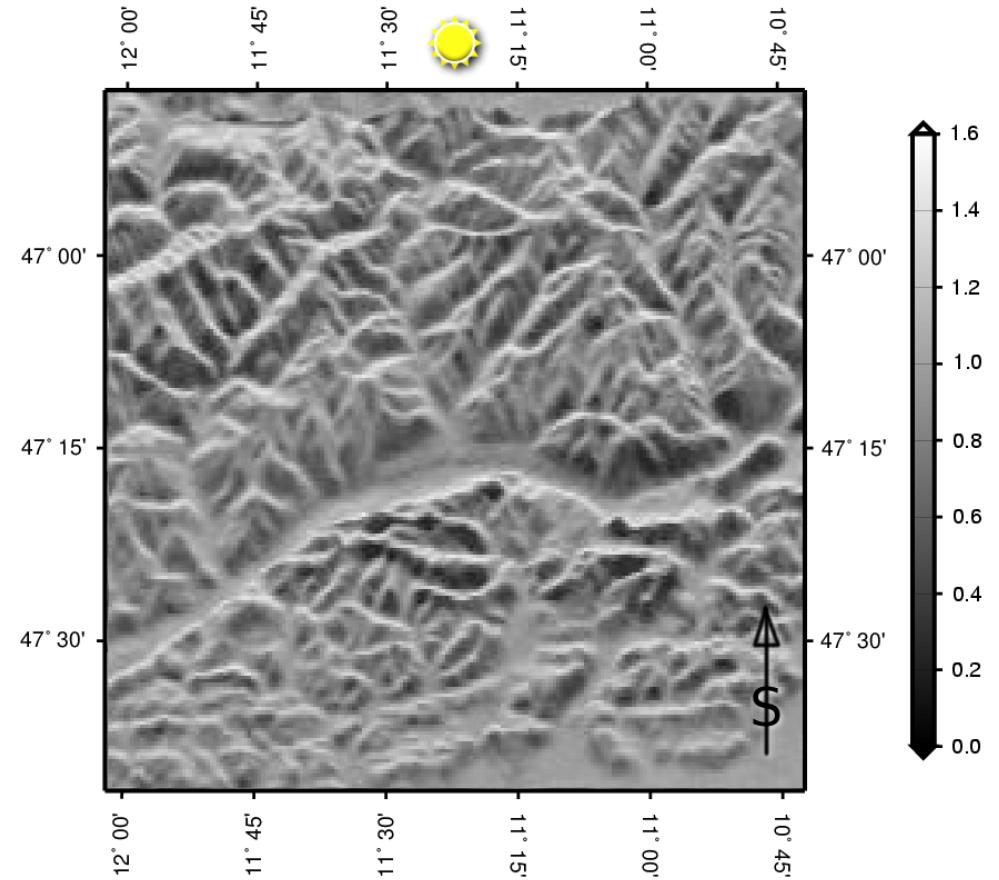


# Surface: Nadir reflectivity at 600 nm

Polar angle 60°, azimuth 0°

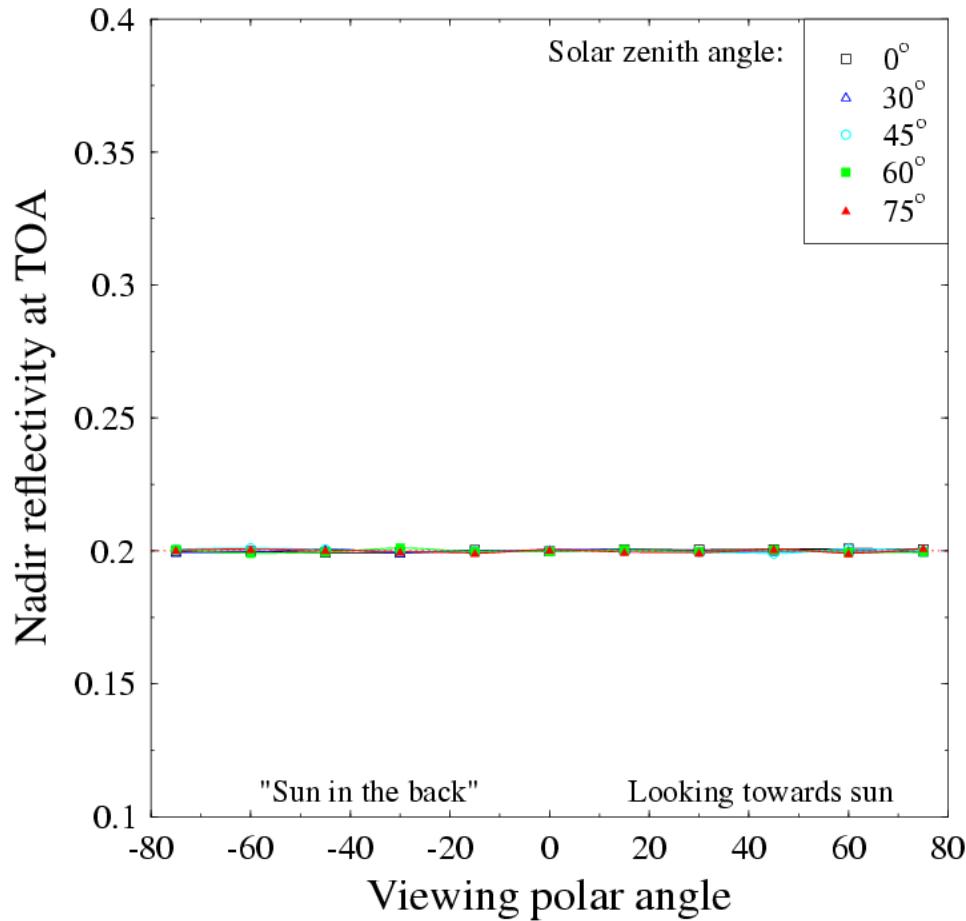


Polar angle 60°, azimuth 180°

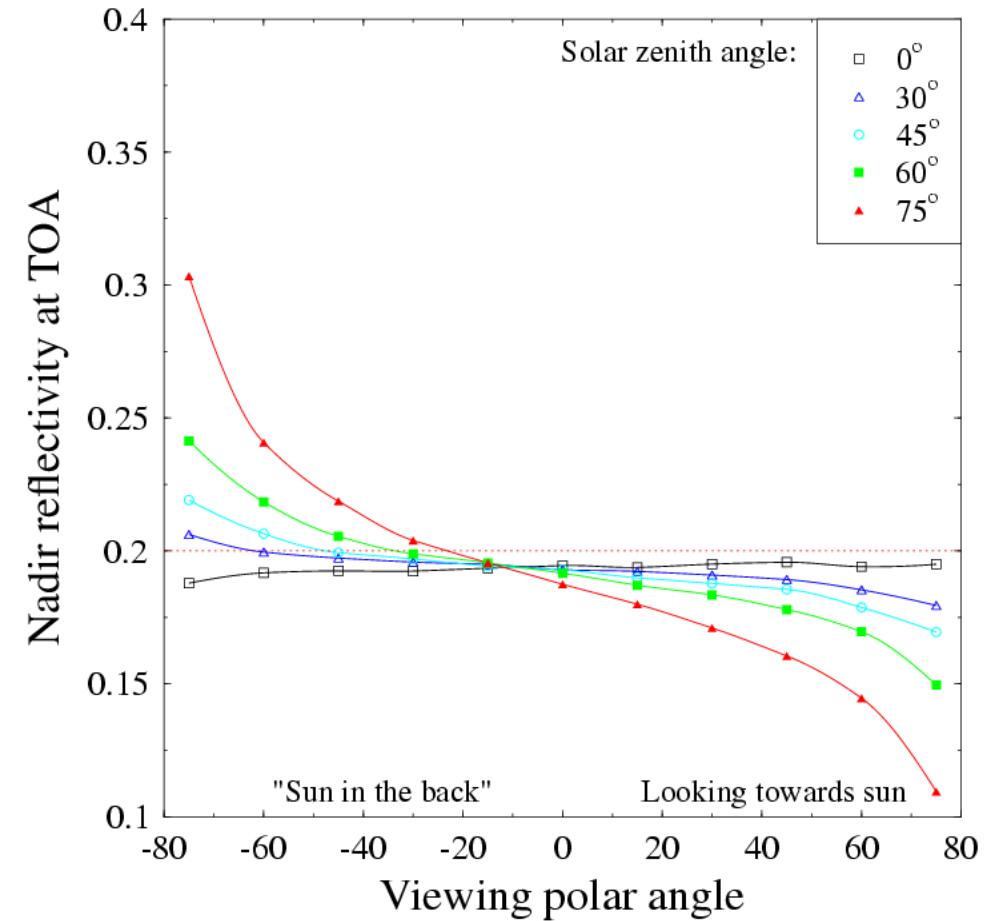


# Surface: The BRDF of the Alps

Surface albedo 0.2, no atmosphere, flat surface



Surface albedo 0.2, no atmosphere



# Conclusions

- Have a look at <http://www.libradtran.org>
- 3D MYSTIC is not part of the free package  
but may be used in close collaboration
- Although clouds are inherently three-dimensional,  
1D approximations are still required for 99%  
of all applications. This will change!